Explosions, Abnormal Loads on Structures

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Abstract— In Kosovo as well as in many countries of the world have occurred explosions in objects, so this research have addressed the ways and possibilities of protecting the buildings by using their position as construction and design elements' after you load resisted by explosions.

This paper presents basic information on the approaches for the evaluation of the blast effects on the structures. Motivation for the present study is recent events happening in the World where more and more structures are being destroyed by unexpected explosions in the urban areas.

Intension of this investigation is to present basic information on what will happen when an explosive device is detonated. Some of the methods to calculate blast loads are presented.

At the end it is presented simple method of designing a reinforced concrete wall barrier subject to a blast load caused by vehicle bomb. Calculation has been carried based on the kinetic energy that is delivered on the surface of the wall and that energy dissipation by the wall to resist such impulse load.

Keywords—Blast resistant design, blast waves, explosive effects.

I.   INTRODUCTION

1.1. Need for Protection

In the last couple of years we are all witnessing that there are more often cases of unexpected explosions, bomb attacks, vehicle bombs, that are striking urban areas. Circumstances, time, actors and reasons for those explosions are unpredictable.

With these events there are more and more people asking questions like:

- If there is need for protection?
- Can we protect our-self and structures?
- Do we need to design structures to resist explosions, etc?

Well, the answer in all these questions definitely will be, yes. From us engineers, it will be required to design and construct special buildings, such as government buildings, embassies, military facilities, bunkers, bridges, silos, industrial facilities, etc. As we can se there is a wide range of buildings that would require to be designed taking in to consideration blast loads as one of the possible load in the load combination.

Constructing structures to resist blast effects is very expensive and often conflicts with architectural solutions and harms the activities for which the structure is designed. For these reasons in most cases it not feasible to construct structures to resist any potential incident.

1.2. Some of the Possible Threats

Of significant importance when designing buildings, in the process of protective design, is assessment of the potential threats.

Some of the primer threats to which structures may be subject are:

- Nuclear device;
- Gas and vapor cloud (Military munitions produce a detonable mixture generating blast loading over a large target area;
- Artillery shells (Fragmenting munitions delivered by heavy artillery which, depending on fusing could penetrate concrete, soil, etc. before detonation.);
- Package bomb (Common device easy infiltrated inside the structures which intension is to create high level of destruction), etc;

In order to withstand the transient loads generated by any of these threats, the elements of the structure need to be both massive and able to absorb large amount of energy. For this reason nearly all purpose-built protective structures are constructed of reinforced concrete.

1.3. What Happens When Explosion Occurs?

When an explosive device is initiated, the explosion reaction generates hot gases which can be at pressure from 100 kilo bars (10000 MPa) up to 300 kilo bars (30000 MPa) at temperatures of about 3000-4000 ºC and have traveling speed of up 7400 m/s. A violent expansion of these explosive gases then occurs and the surrounding air is forced out of the volume it occupies. As a consequence a layer of compressed air-blast wave- forms in front these gases containing most of the energy released by the explosion. (**Bulson, Philip. :**Explosive Loading Of Engineering Structures**,** University of Southampton, 1997)
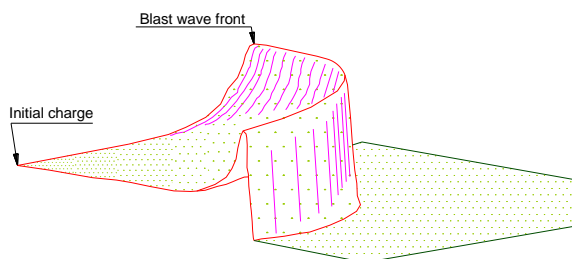
Fig. 1:Blast Wave

The violent release of energy from a detonation in a gaseous medium gives rise to a sudden pressure increase in that medium. The pressure disturbance, termed as the blast wave, is characterized by an instantaneous rise from the ambient pressure, $\underline{Po}$, to peak incident pressure $\underline{Pso}$. At a point away from the blast, the pressure wave has almost a triangular shape as shown in Fig.2. The shock front arrives and after the rise to the peak value the incident pressure decays to an ambient value in the time, $\underline{td}$, described as the positive phase duration. This is followed by a negative phase, $\underline{tng}$, and characterized by a pressure below the pre-shot ambient pressure and a reversal of the particle flow. The negative phase is usually less important in a design than the positive phase. [2]
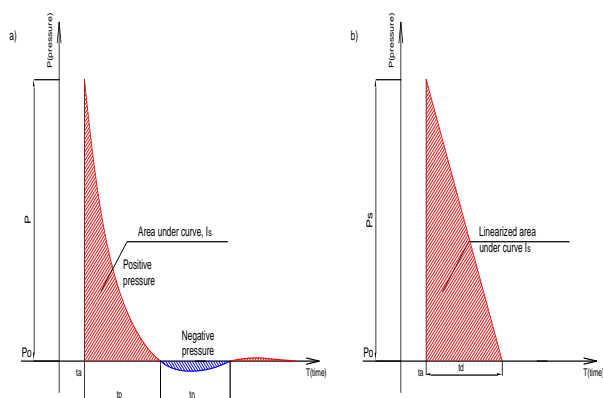

Fig. 2: Typical and Linearized Blast Pressure Wave

The equations of motion that describe a blast wave are very complex. Initially numerically these were solved by Brode and experimentally verified by Kingery. A good knowledge of the gas dynamics is needed for more comprehensive treatment
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II. EQUATIONS TO DETERMINE BLAST PRESSURE

Extensive research has been conducted to predict the peak pressure values, impulse velocities and other parameters of blast waves. Most of the theoretical models and graphs were done by military research centers, in which they correlate between a scaled distance Z and the predicted peak pressures.

R- Radial standoff distance from the center of the explosive to a particular location on a structure, meters

W- Charge weight of TNT, kilograms.[1], [2]

As TNT is as considered as reference type of explosion, all other explosives need to be converted in to TNT equivalent. Table below shows conversion factors for some types of explosives:

Table.1: Conversion factors for explosives

Explosive	Specific energy Qx(kJ/kg)*	TNT Equivalent Qx/QTNT
Mixture B (60% RDX, 40% TNT)	5190	1.148
RDX (Cyclonite)	5360	1.185
HMX	5680	1.256
Nitroglycerine (liquid)	6700	1.481
TNT	4520	1.000
Pentolit	6012	1.330
60% Nitroglycerine dynamite	2710	0.600
Semtex	5660	1.250

The scaled distance parameter in fact presents law on blast estimating. This law says: Similar blast waves are produced at incidental scaled distance when two explosive charges of similar geometry and of the same explosive type, but of different sizes, are detonated in the same atmosphere.

Various equations by different authors are given to determine blast pressure. An empirical equation is presented by Charles N. Kingery and Gerald Bulmash with reflected pressure coefficients, are listed in the US Army technical manual TM5-855-1. This equation computed air blast environment created by the detonation of a hemispherical TNT explosive source at sea level. Information on this model is classified and therefore is not for public use.

Another empirical equation presented by the Defense Atomic Support Agency, DASA report # 1860 (1966). This equation correlates between the peak pressure with the weight and standoff distance as shown in equation:

$Ps = 1033.5*W*(5/R)^3$ (2)

Ps: Peak pressure at given charge weight and standoff distance in [kPa]

W: Charge weight of TNT, kilograms [kg]

R- Radial standoff distance from the center of the explosive to a particular location on a structure, metersAnother equation from experimental researches is:

$Ps = 45956*W*R-2.5$ (3)

The incident impulse associated with the blast wave is the integrated area under the pressure time curve and is denoted as $\underline{Iso}$. To simplify the blast resistant design

$Z = R/W^{1/3}$ (1)

procedure, the generalized blast wave profile shown in fig.3a is usually linearized as illustrated in fig.3b.

Value of the impulse can be calculated as the area of the triangle under the linearized blast curve:

Iso=(Pso*td)/2   (4)

Equation given by author Friedlander calculates blast pressure taking in to the consideration time factor

$$p(t) = p_s \left[1 - \frac{t}{T_s} \right] \exp \left\{ -\frac{bt}{T_s} \right\} \qquad (5)$$

Of course, these days in the market there are several applicative software's that easily calculate blast pressure and other parameters, including structural analysis. Some of them are: At-Blast, Nonlin CONWEP, ABACUS, Pronto3D, etc.[1]

2.1 Blast Effects on the Structures

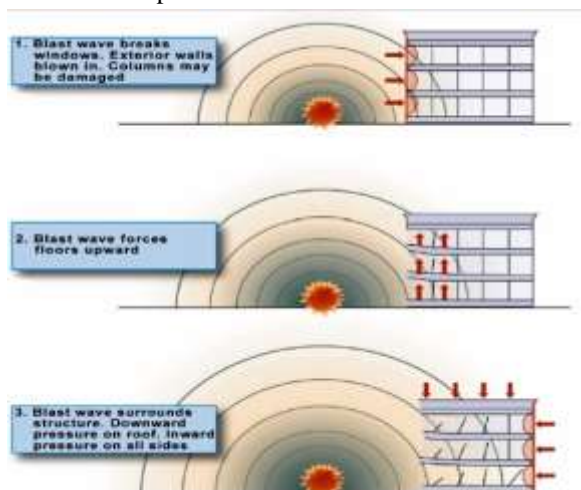Figure 3present what happens to a frame structure when a vehicle bomb explodes in front.

Fig. 3:Explosion in Front of the Structure

As far as the nuclear explosions are concerned, there is only one well known event, which happened during the Second World War when two bombs were thrown in the towns of Hiroshima and Nagasaki in Japan.

Number of explosions caused by vehicle bombs or packed bombs if much bigger. [3], [4].

Table below presents average quantities that can be carried by different means of transportations. This table is important as it can be used as a good start point to predict and calculate possible blast pressure.[1]

Table.2: Conversion factors for explosives

Type of transportation	Capacity (TNT equivalent)
Pipe bomb	up to 2.5 kg
Suitcase bomb	up to25 kg
Vehicle bomb-small vehicle	up to 250 kg
Vehicle bomb-sedan	up to 450 kg
Vehicle bomb-van	up to 2000 kg
Truck	up to 4500 kg
Truck-tanker	up to 14000 kg
Truck-lorry	up to 30000 kg

On this study will present two of the many cases, just for the comparison and presentation of the scale of the devastation that can be caused by vehicle bomb blast Fig. 4.

Fig. 4 a) Khobar Towers, US Marines HQ, Saudi Arabia, 1996 Explosive, 9 ton TNT equivalent, standoff, 25m 19 victims, 450 injured,

Fig. 4 b) Federal building A.P Murrah, Oklahoma City, USA 1995 Explosive, 1.8 ton TNT equivalent, standoff 4.5 m 168 victims, 500 injured

Loads to be protected from explosions important is the way the building is built, it is noticed by explosions that have destroyed Mail in Pristina object in relation to objects around fig. 5.

Fig. 5: Destruction of buildings with poor material compared with those of reinforced concrete

Serious injuries and fatalities in humans, cause the equipment and artillery, it can be seen from the recent war in Prekaz – Kosovo, fig 6.

Fig.6: Damaged facilities in Kosovo (Prekaz) during the Kosovo war

III.   COMPARISONS OF SEISMIC AND BLAST LOADING

In general similarities between seismic and blast loading includes the following:

- Dynamic loads and dynamic structural response;
- Involve inelastic structural response;
- Focus on life safety as opposed to preventing structural damage;
- Nonstructural damage and hazards;
- Similar: performance based design; life safety issues; progressive collapse; structural integrity; ductility, continuity and redundancy; balanced design.

Differences between these two types of loading include (fig. 5):

- Blast loading is due to a propagating pressure wave as opposed to ground shaking;
- Blast results in direct pressure loading to structure; pressure is in all directions, whereas a seismic event is dominated by lateral load effects;
- Blast loading is of higher amplitude and very short duration compared with a seismic event;

- Magnitude of blast loading is difficult to predict and not based on geographical location;
- Blast effects are confined to structures in the immediate vicinity of event because pressure decays rapidly with distance; local versus regional event;
- Progressive collapse is the most serious consequence of blast loading;
- Slab failure is typical in blasts due to large surface area an upward pressure not considered in gravity design;
- Small database on blast effects on structures;
- Seismic-resistant design is mature compared with blast-resistant design.

In summary, while the effect of blast loading is localized compared with an earthquake, the ability to sustain local damage without total collapse (structural integrity) is a key similarity between seismic-resistant and blast-resistant design.
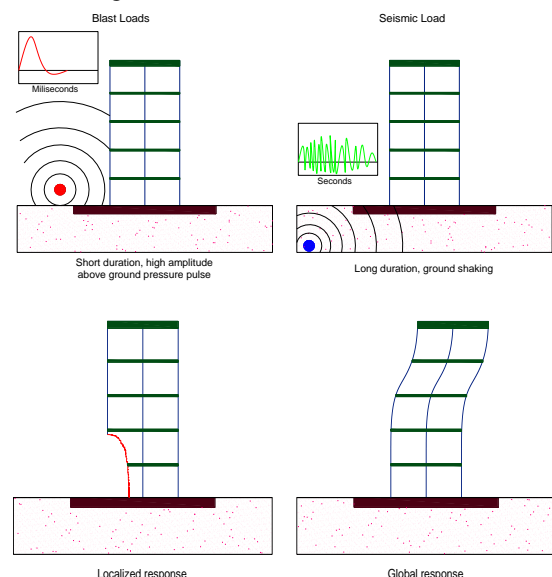

Fig. 5: Comparison of blast and seismic loading (top) and the structural response (bottom)

IV.   SOME OF THE COMMON DESIGN REQUIREMENTS - TECHNICAL DESIGN MANUALS FOR BLAST-RESISTANT DESIGN

4.1 In General

American Standards, Unified Facilities Criteria, UFC 4-010-01 requires that all new and existing buildings of three stories or more be designed to avoid progressive collapse.   Progressive collapse is defined in the commentary of the ASCE (American Society of Civil Engineers) 7-02 as "the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it.

4.2. Design Approaches

ASCE 7-02 defines two general approaches for reducing the possibility of progressive collapse: Direct Design and Indirect Design.

Direct design approach

Direct Design approaches include "explicit consideration of resistance to progressive collapse during the design process…" These include:

- Alternate Path (AP)
- Specific Local Resistance (SLR)

Indirect design approach

With Indirect Design, resistance to progressive collapse is considered implicitly "through the provision of minimum levels of strength, continuity and ductility". ASCE 7-02 presents general design guidelines and suggestions for improving structural integrity. These include:

od plan layout, integrated system of ties, returns on walls, changing span directions of floor slabs, load-bearing interior partitions, catenaries action of the floor slab, beam action of the walls, redundant structural systems, ductile detailing, compartmentalized construction.

However, no quantitative requirements for either direct or indirect design to resist progressive collapse are provided in ASCE 7-02.

The British Standards employ three design approaches for resisting progressive collapse:

- Tie Forces (TF), Alternate Path (AP), Specific Local Resistance (SLR).

The provisions specified that progressive collapse potential is limited if the damaged area is smaller of the following:5% of the area of the story or 70 m²

Fig.7: Progressive Collapse Ronan Point, UK, 1968[3]

4.3. Some of the Common Design Requirements - TECHNICAL DESIGN MANUALS FOR **BLAST-RESISTANT DESIGN**

This section summarizes applicable military design manuals and computational approaches to predicting blast loads and the responses of structural systems. Although the majority of these design guidelines were focused on military applications these knowledge are relevant for civil design practice. [5]

A Manual for the Prediction of Blast and Fragment Loadings on Structures, DOE/TIC- 11268 (U.S. Department of Energy, 1992). This manual provides guidance to the designers of facilities subject to accidental explosions and aids in the assessment of the explosion-resistant capabilities of existing buildings.[5]

The Design and Analysis of Hardened Structures to Conventional Weapons Effects (DAHS CWE, 1998). This new Joint Services manual, written by a team of more than 200 experts in conventional weapons and protective structures engineering, supersedes U.S. Department of the Army TM 5- 855-1, Fundamentals of Protective Design for Conventional Weapons (1986), and Air Force Engineering and Services Centre ESL-TR-87-57, Protective Construction Design Manual (1989)[5]Columns and Walls - For all levels of protection, all multistory vertical load-carrying elements must be capable of supporting the vertical load after the loss of lateral support at any floor level (i.e., a laterally unsupported length equal to two stories must be used in the design or analysis

- **Upward Loads on Floors and Slabs-** In each bay and at all floors and the roof, the slab/floor system must be able to withstand a net upward load of the following magnitude:

$$1.0\,D + 0.5\,L \quad (6)$$

D- Dead load based on self-weight only (kN/m²) ,

L- Live load (kN/m²)

This load is applied to each bay, one at a time, i.e., the uplift loads are not applied concurrently to all bays. Floor systems in each bay and its connections to the beams, girders, columns, capitals, etc, shall be designed to carry this load. A load path from the slab to the foundation for this upward load does not need to be defined.).[5]
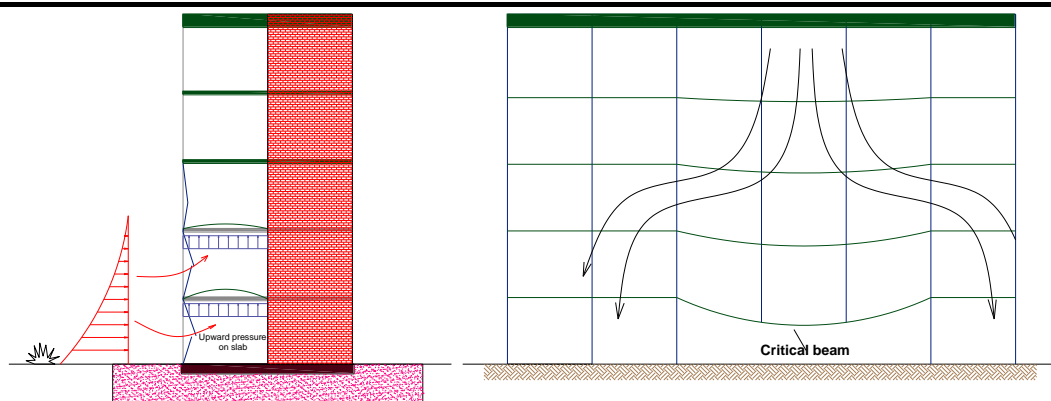
Fig.8: Uplift Loads for Slabs on the Structures Subject to Blast Loads

V.   CONCLUSION

Even though all that has been presented in this document presents a small part on evaluation of the structures under the blast loads, still there are some conclusions that can be made:

- Explosions cause extreme loads on structures;
- Blast loads have nature of impulsive loads, high intensity and load duration is shorter compare to seismic loads;
- Keeping the standoff distance is the best way to mitigate effects of the blast loads;
- Progressive collapse is the worst effect on the structures that can be generated by blast loads;
- During the Kosovo war the impact of material objects in tackling explosions;
- With better protection from explosions is respect and love between people regardless of religion and race.

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